

Whole Effluent Toxicity

Learning Objectives

- ◆ **Foster better understanding of scientific underpinnings of WET**
 - **Describe uses and limitations**
- ◆ **Discuss WET implementation and methods requirements**
- ◆ **Explain the purpose of toxicity reduction evaluations**
- ◆ **Show how WET is similar to chemical evaluations**

What is Whole Effluent Toxicity (WET) Testing?

- ◆ Part of water quality-based toxics control approach
- ◆ Measures the aggregate toxic effect of effluent or ambient water
 - measures the response of exposed aquatic organisms

Why WET?

- ◆ Allows for the protection of the narrative criterion “no toxics in toxic amounts”
 - Implementation Policy
- ◆ Integrated Approach to Water Quality-Based Toxics Control
 - Chemical specific approach
 - Biological criteria approach
 - Whole effluent toxicity approach

Acute Toxicity

- ◆ Acute Tests
 - Test duration: 96 hours or less
 - Endpoint: Mortality (expressed as LC₅₀)
 - Example: *Pimephales promelas* (fathead minnow) 96 hour test

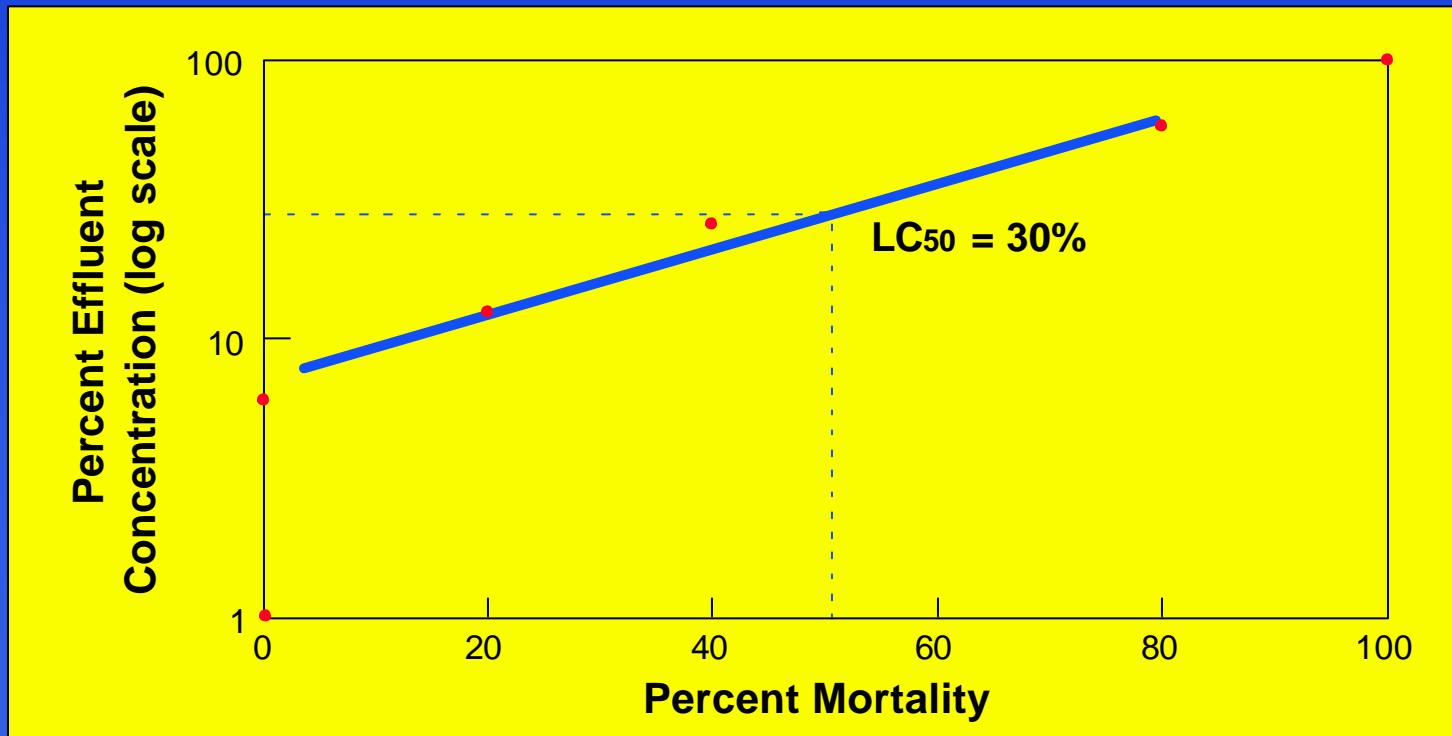
Chronic Toxicity

- ◆ Short-term Chronic Tests
 - Test duration: 1.5 hours (sea urchins) to 7-day survival and growth test (sheepshead minnows)
 - Endpoint: Growth, reproduction, etc., (expressed as NOEC, LOEC, or IC₂₅)
 - Example: *Ceriodaphnia dubia* (water flea) 3-day brood survival and reproduction test

Acute WET Statistical Endpoints: Definitions

- ◆ **LC₅₀**
 - Concentration of effluent that is lethal to 50 percent of the exposed organisms
 - uses a dilution series
- ◆ **pass/fail**
 - Instream waste concentration (IWC) or ambient toxicity test measured against a control

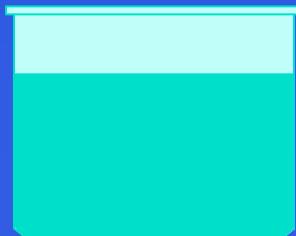
Example of Acute Test Data and Statistical Analysis



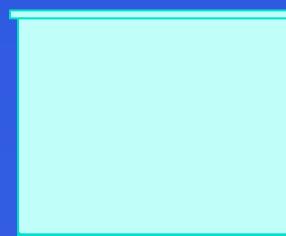
Example of Pass/Fail Acute Test at IWC or Ambient

- ◆ Instream Waste Concentration (IWC) equals 75%
- ◆ Statistical evaluation using student-t test compares mortality rates of ambient or IWC sample against the control
 - Is there a “significant statistical difference”?

IWC = 75%



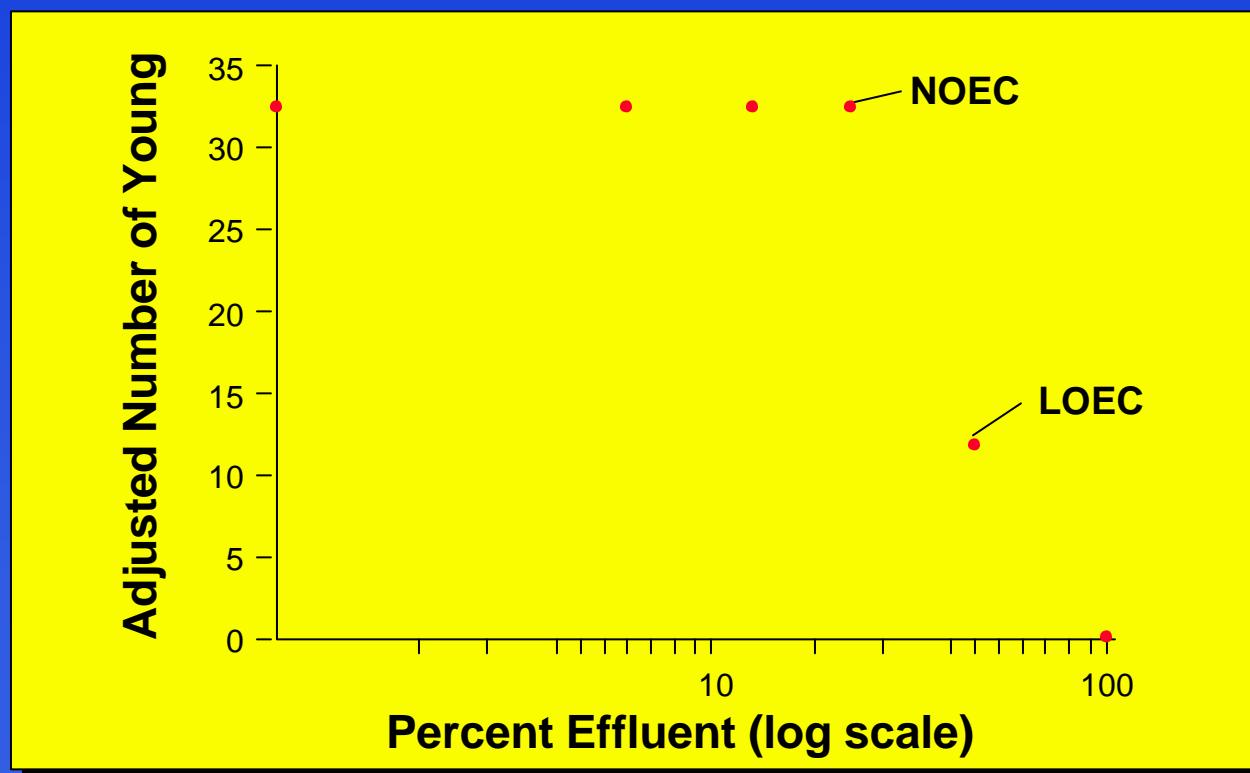
Lab Control



Chronic WET Statistical Endpoints (Hypothesis Testing)

- ◆ NOEC
 - No Observed Effect Concentration (NOEC) - the highest concentration of an effluent or a toxicant at which no adverse effects are observed on the aquatic test organisms

Example of Chronic Test Data

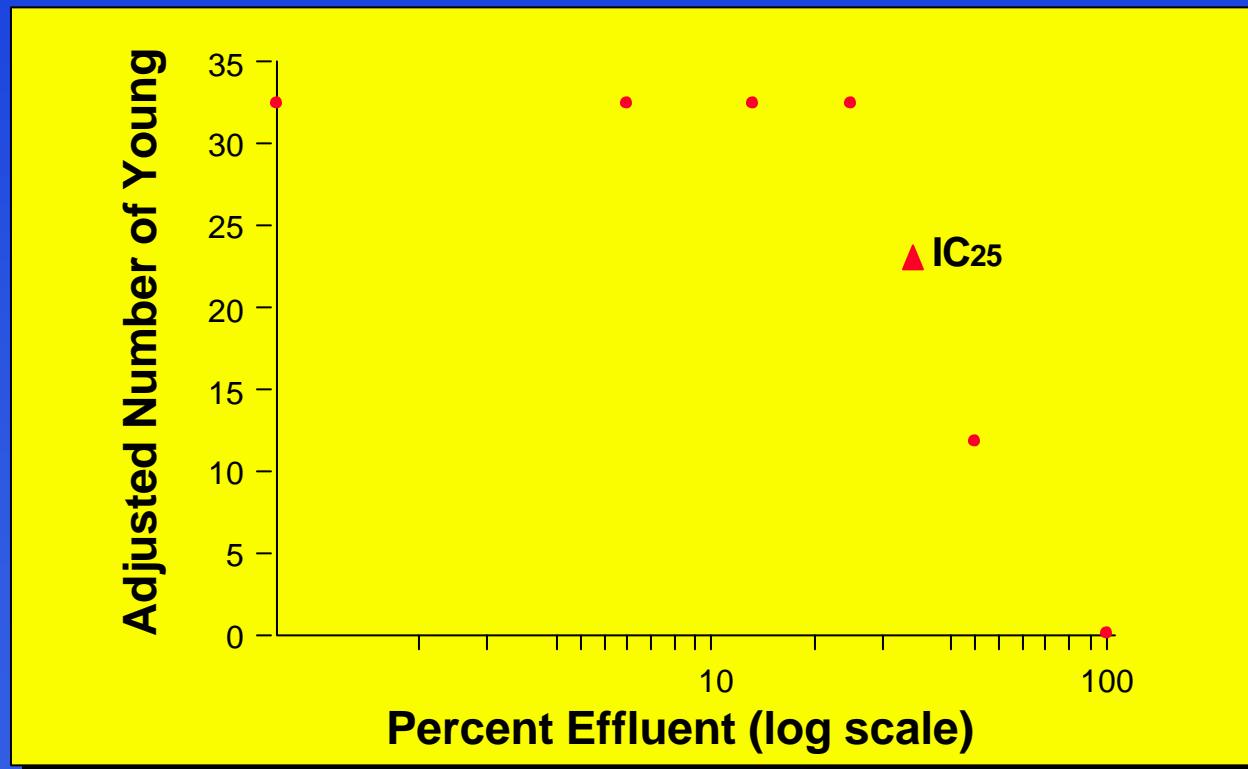


Chronic WET Statistical Endpoints (Point Estimates)

Inhibition Concentration (IC_p)

- ◆ A point estimate of the toxicant or effluent concentration that would cause:
 - (IC_p) a given percent reduction in a nonlethal biological measurement of the test organisms (e.g., reproduction, growth)

Example of Determining an IC₂₅ from Chronic Test Data



Considerations When Selecting Toxicity Test Methods

- ◆ Approved acute and chronic methods found in 40 CFR Part 136
- ◆ Must determine:
 - Acute or chronic toxicity (based on calculated limits or available dilution)
 - Fresh water or marine discharge
 - Most appropriate species (e.g., three species quarterly for 1 year)

Options for Expressing WET Values

- ◆ Option A

- Use statistical endpoint (e.g., LC₅₀, NOEC, LOEC, or IC₂₅) directly

Example: LC₅₀ = 30% effluent

- ◆ Option B

- Use toxic units

$$TU_a = \frac{100}{LC_{50}}$$

$$TU_c = \frac{100}{NOEC}$$

Examples of Toxic Units

- ◆ Acute (TUa)

- Assuming LC₅₀ = 28%

$$\text{TUa} = \frac{100}{\text{LC}_{50}} = \frac{100}{28} = 3.6$$

- ◆ Chronic (TUC)

- Assuming NOEC = 50%

$$\text{TUC} = \frac{100}{\text{NOEC}} = \frac{100}{50} = 2.0$$

- Assuming IC₂₅ = 30%

$$\text{TUC} = \frac{100}{\text{IC}_{25}} = \frac{100}{30} = 3.3$$

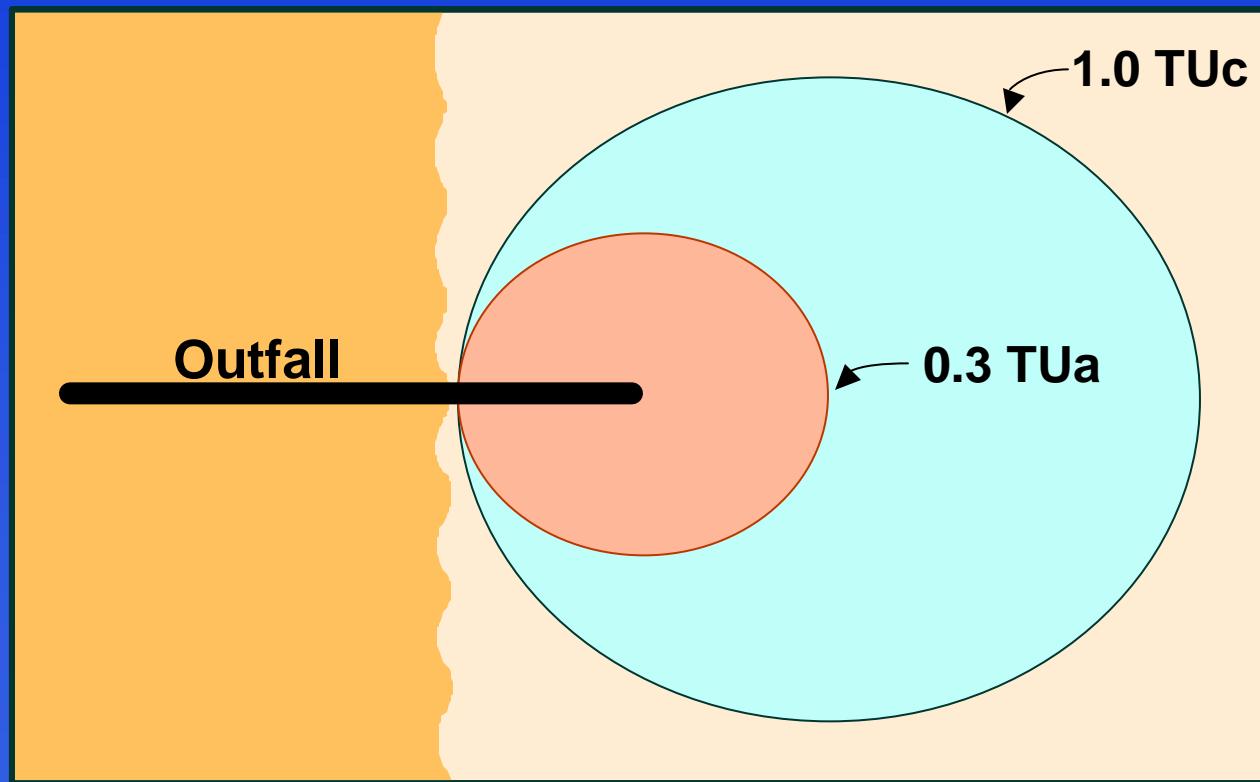


Whole Effluent Toxicity Criteria

- ◆ **Narrative** - “no toxics in toxic amounts”
- ◆ **Numeric** - (TSD recommendations) or (numeric interpretation of Narrative)
 - Acute = 0.3 TUa (e.g., $\frac{100}{LC_{50}}$)
 - Chronic = 1.0 TUc (e.g., $\frac{100}{NOEC}$)

Whole Effluent Toxicity Criteria (Continued)

Applying toxicity criteria with allowable dilution:



Steps in Developing Chemical-Specific Water Quality-Based Effluent Limits

Acute and Chronic Wasteload Allocations (WLAs)



Step 1: Calculate Long-Term Average (LTA) for Both WLAs



Step 2: Select Lowest LTA



Step 3: Calculate Maximum Daily Limit (MDL) and Average Monthly Limit (AML)

Steps in Developing WET Permit Limitations

Acute and Chronic Wasteload Allocations

Additional Step: Convert Acute WLA into Chronic WLA (WET only)

Step 1: Calculate LTA for Both

Step 2: Select Lowest LTA

Step 3: Calculate Maximum and Average Limits

Definition of Acute-Chronic Ratio

- ◆ **Acute-chronic ratio (ACR) - the ratio of the acute toxicity of an effluent or a toxicant to its chronic toxicity**
- ◆ **Calculated as the average of the ratios between at least 10 pairs of acute and chronic toxicity test results for the same species**
- ◆ **Default ACR = 10 in the absence of data to develop an ACR**

Example ACR Calculations

Using test results expressed as percent effluent:

$$\text{ACR} = \frac{\text{LC}_{50}}{\text{NOEC}} = \frac{65\%}{25\%} = 2.6$$

Using test results expressed as toxic units:

$$\text{ACR} = \frac{\text{TUc}}{\text{TUa}} = \frac{4.0}{1.5} = 2.6$$

Why an ACR?

- ◆ Acute and chronic toxicity test results are not directly comparable
- ◆ ACR is a factor for estimating chronic toxicity on the basis of acute toxicity data, or for estimating acute toxicity on the basis of chronic toxicity data
- ◆ Allows expression of toxicity results or requirements in the same units

Example Step 1

WLAa = 1.5 TUa

WLAc = 16 TUc

Observed ACR = 8.0

WLA_{a,c} = Acute WLA expressed in TUc

WLA_{a,c} = WLAa x ACR

$$= \cancel{1.5 \text{ TUa}} \times 8.0 \left(\frac{\text{TUc}}{\cancel{\text{TUa}}} \right) = 12 \text{ TUc}$$

Steps in Developing WET Permit Limitations

Acute and Chronic Wasteload Allocations

Additional Step: Convert Acute WLA into Chronic WLA (WET only)

Step 1: Calculate LTA for Both

Step 2: Select Lowest LTA

Step 3: Calculate Maximum and Average Limits

Toxicity Reduction Evaluations

- ◆ **What is a TRE?**
 - Procedures for investigating the causes and identifying corrective actions for effluent toxicity problems
- ◆ **Why are TREs necessary?**
 - Achieve compliance with limits or requirements for effluent toxicity contained in NPDES permits

Toxicity Reduction Evaluations (Continued)

- ◆ How are TREs performed?
- ◆ Site-specific study designed to:
 - Identify the causative agents of effluent toxicity
 - Isolate the sources of the toxicity
 - Evaluate the effectiveness of toxicity control options
 - Confirm the reduction in effluent toxicity

Mechanisms for Requiring TREs

- ◆ Special conditions in NPDES permit
- ◆ Section 308 letter
- ◆ Section 309 Administrative Order or a Consent Decree

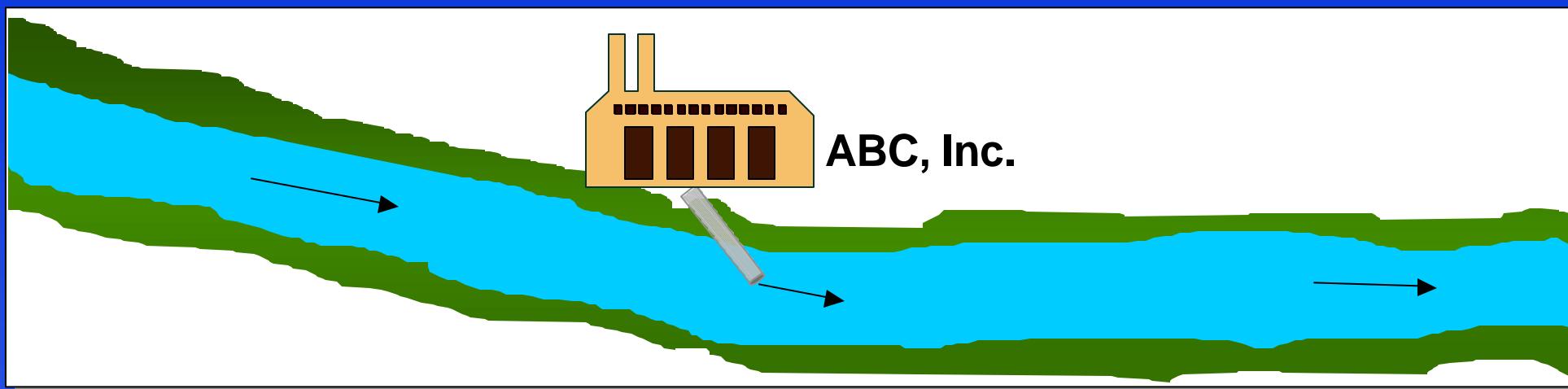
Permits Must Specify

- ◆ Test species and method
- ◆ Testing frequency
- ◆ Statistical endpoints
- ◆ Steps to address toxicity

WET Example

Developing WET Effluent Limits

What is the Maximum Allowable Whole Effluent Toxicity for the ABC, Inc. Effluent Assuming Complete Mixing?



Q_s = Upstream river flow

$1Q_{10}$ = 1.2 cfs

$7Q_{10}$ = 3.6 cfs

Q_d = Discharge flow = 0.31 cfs

C_s = Upstream river concentration = 0 TUC

C_r = Water quality criteria

Acute = 0.3 TUa applied at 1Q10 low flow

Chronic = 1.0 TUC applied at 7Q10 low flow

Acute WLA

$$Cd = \frac{Cr(Qd + Qs) - CsQs}{Qd}$$

$$Cd \text{ Acute} = \frac{0.3 (0.31 + 1.2) - (0)(1.2)}{0.31}$$

$$Cd \text{ Acute} = WLA_a = 1.5 \text{ TUa}$$

Chronic WLA

$$Cd = \frac{Cr(Qd + Qs) - CsQs}{Qd}$$

$$Cd \text{ chronic} = \frac{1.0 (0.31 + 3.6) - (0)(3.6)}{0.31}$$

$$Cd \text{ chronic} = WLA_c = 13 \text{ TUC}$$

Step 1: Convert Acute WLA into Chronic Toxic Units

Observed ACR = 10

$WLA_{a,c}$ = Acute WLA expressed in TUc

$WLA_{a,c} = WLA_a \times ACR$

$$= 1.5 \text{ TUa} \times 10 \left(\frac{\text{TUc}}{\text{TUa}} \right) = 15 \text{ TUc}$$

Step 2: Calculate LTAs

CV	WLA multipliers	
	$e^{[0.5s^2 - z_s]}$	
	95th percentile	99th percentile
0.1	0.853	0.797
0.2	0.736	0.643
0.3	0.644	0.527
0.4	0.571	0.440
0.5	0.514	0.373
0.6	0.468	0.321
0.7	0.432	0.281
0.8	0.403	0.249
0.9	0.379	0.224
1.0	0.360	0.204
1.1	0.344	0.187
1.2	0.330	0.174
1.3	0.319	0.162
1.4	0.310	0.153
1.5	0.302	0.144
1.6	0.296	0.137
1.7	0.290	0.131
1.8	0.285	0.126
1.9	0.281	0.121
2.0	0.277	0.117

Acute LTA

$$CV = 0.6$$

$$WLAA,c = 15 \text{ TUC}$$

= 99th percentile value

$$LTAA,c = 15 \text{ TUC} \times 0.321 = 4.8 \text{ TUC}$$



Step 2: Calculate LTAs

CV	WLA multipliers	
	$e^{[0.5s_4^2 - z_{s_4}]}$	
	95th percentile	99th percentile
0.1	0.922	0.891
0.2	0.853	0.797
0.3	0.791	0.715
0.4	0.736	0.643
0.5	0.687	0.581
0.6	0.644	0.527
0.7	0.606	0.481
0.8	0.571	0.440
0.9	0.541	0.404
1.0	0.514	0.373
1.1	0.490	0.345
1.2	0.468	0.321
1.3	0.449	0.300
1.4	0.432	0.281
1.5	0.417	0.264
1.6	0.403	0.249
1.7	0.390	0.236
1.8	0.379	0.224
1.9	0.369	0.214
2.0	0.360	0.204

Chronic LTA

$$CV = 0.6$$

$$WLAc = 13 \text{ TUC}$$

= 99th percentile value

$$LTAc = 13 \text{ TUC} \times 0.527 = 6.9 \text{ TUC}$$

Step 3: Select Lowest LTA

$$LTA_{a,c} = 4.8 \text{ TUC}$$

$$LTAc = 6.9 \text{ TUC}$$

Select $LTA_{a,c} = 4.8 \text{ TUC}$

Step 4: Calculate MDL and AML

CV	LTA multipliers	
	$e^{[zs - 0.5s^2]}$	
	95th percentile	99th percentile
0.1	1.17	1.25
0.2	1.36	1.55
0.3	1.55	1.90
0.4	1.75	2.27
0.5	1.95	2.68
0.6	2.13	3.11
0.7	2.31	3.56
0.8	2.48	4.01
0.9	2.64	4.46
1.0	2.78	4.90
1.1	2.91	5.34
1.2	3.03	5.76
1.3	3.13	6.17
1.4	3.23	6.56
1.5	3.31	6.93
1.6	3.38	7.29
1.7	3.45	7.63
1.8	3.51	7.95
1.9	3.56	8.26
2.0	3.60	8.55

MDL

CV = 0.6

MDL = 99th percentile value

MDL = 4.8 TUC x 3.11 = 15 TUC

Step 4: Calculate MDL and AML

CV	LTA multipliers									
	95th percentile					99th percentile				
	n=1	n=2	n=4	n=8	n=30	n=1	n=2	n=4	n=10	n=30
0.1	1.17	1.12	1.08	1.06	1.03	1.25	1.18	1.12	1.08	1.04
0.2	1.36	1.25	1.17	1.12	1.06	1.56	1.37	1.25	1.16	1.08
0.3	1.55	1.38	1.26	1.18	1.09	1.90	1.59	1.40	1.24	1.13
0.4	1.75	1.52	1.36	1.25	1.12	2.27	1.83	1.55	1.33	1.18
0.5	1.96	1.66	1.45	1.31	1.16	2.68	2.09	1.72	1.42	1.23
0.6	2.13	1.90	1.55	1.38	1.19	3.11	2.37	1.90	1.52	1.28
0.7	2.31	1.94	1.65	1.45	1.22	3.56	2.66	2.08	1.62	1.33
0.8	2.48	2.07	1.75	1.52	1.26	4.01	2.96	2.27	1.73	1.39
0.9	2.64	2.20	1.85	1.59	1.29	4.46	3.28	2.48	1.84	1.44
1.0	2.78	2.33	1.95	1.66	1.33	4.90	3.59	2.68	1.96	1.50
1.1	2.91	2.45	2.04	1.73	1.36	5.34	3.91	2.90	2.07	1.56
1.2	3.03	2.56	2.13	1.80	1.39	5.76	4.23	3.11	2.19	1.62
1.3	3.13	2.67	2.23	1.87	1.43	6.17	4.55	3.34	2.32	1.68
1.4	3.23	2.77	2.31	1.94	1.47	6.56	4.86	3.56	2.45	1.74
1.5	3.31	2.86	2.40	2.00	1.50	6.93	5.17	3.78	2.58	1.80
1.6	3.38	2.95	2.48	2.07	1.54	7.29	5.47	4.01	2.71	1.87
1.7	3.45	3.03	2.56	2.14	1.57	7.63	5.77	4.23	2.84	1.93
1.8	3.51	3.10	2.64	2.20	1.61	7.95	6.06	4.46	2.98	2.00
1.9	3.56	3.17	2.71	2.27	1.64	8.26	6.34	4.68	3.12	2.07
2.0	3.60	3.23	2.78	2.33	1.68	8.55	6.61	4.90	3.26	2.14

AML

Number of samples = 4

CV = 0.6

AML = 95th percentile value

$$\text{AML} = 4.8 \text{ TUc} \times 1.55 = 7.4 \text{ TUc}$$

